LESSON 31 – CLUTTER

So far, we've only investigated how radar returns from our intended target. Adding ground to the picture complicates things a lot. We'll take a quick survey of how ground clutter affects radar returns and ways to minimize its effects.

Reading:

Stimson **Ch. 22, Ch. 23**

Problems/Questions:

Work on Problem Set 4

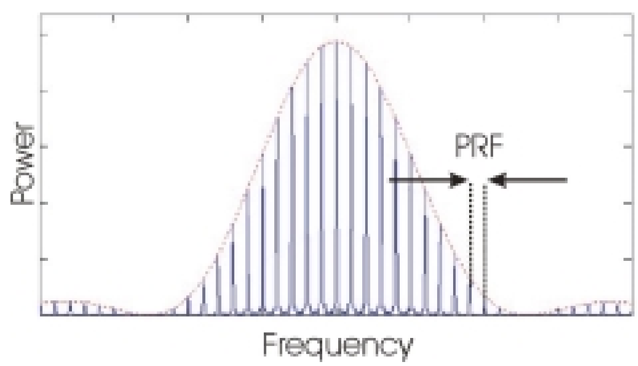
Objectives:

31-1 Understand the factors that affect the ground clutter.
31-2 Understand ways to minimize ground clutter effects.
31-3 Understand effects of ground clutter on target radar returns.

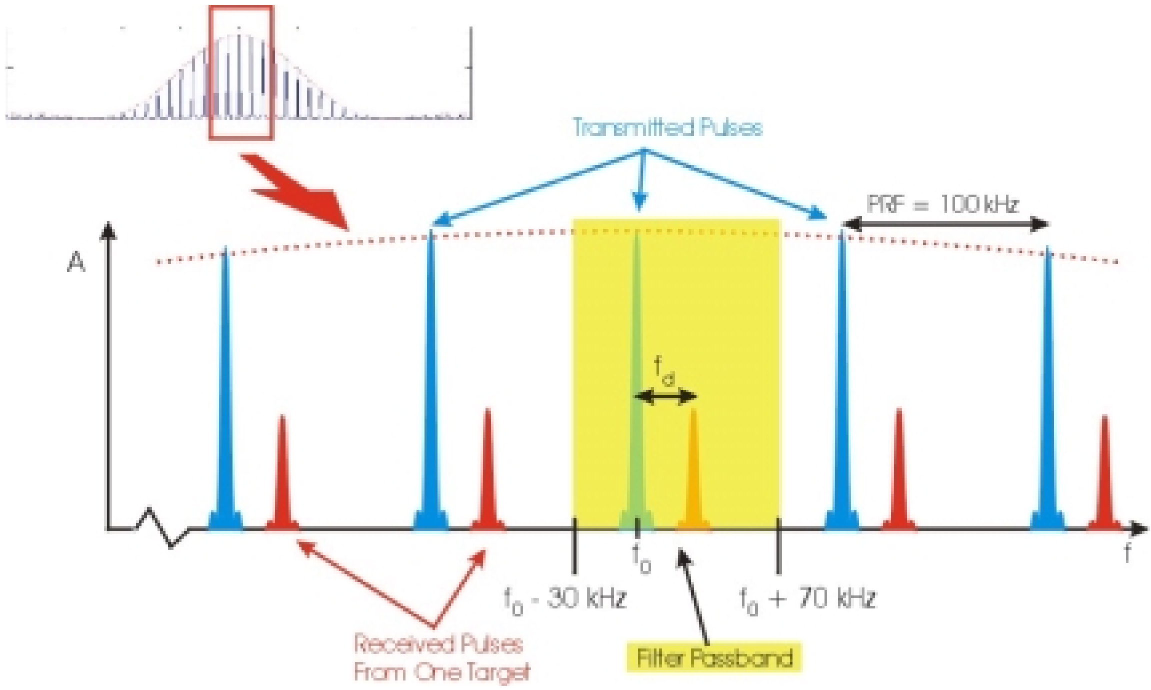
Last Time: Sensing Doppler frequencies
Implementation
PRF Considerations
Doppler Ambiguities

Today: Doppler Ambiguities
Clutter

Last lesson, we saw that for current hardware limitations, it is impossible to transmit only one frequency, which would be the only way to completely avoid Doppler ambiguities. In fact, we saw that in most cases, there were *hundreds* of significant (stronger than noise) frequencies transmitted within the main lobe of the single-pulse spectrum.

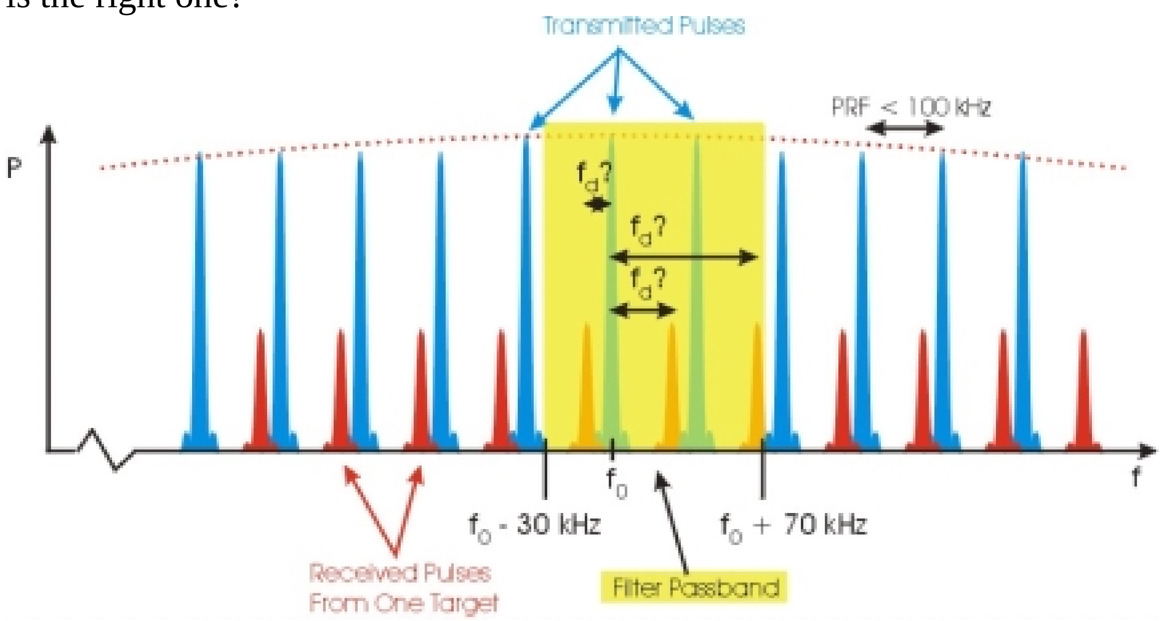


We also saw that in practice, it was not necessary to actually transmit a single frequency, since the expected Doppler shifts were so much smaller than the single pulse BW_{nn}. We calculated a required filter *passband*, a band of frequencies large enough to accommodate the maximum closing and opening velocities expected to be encountered. By ensuring that our PRF was larger than our passband, we eliminated Doppler ambiguities.



Review line shape, line spacing/PRF, passband, Doppler shift, and amplitudes on this plot.

What happens to this spectrum if the PRF is decreased? One target shows up multiple places in the filter bank. How do we know which Doppler shift is the right one?



The most common way to resolve Doppler ambiguities is the same way we resolved range ambiguities – PRF switching.

Review PRF Switching vs. PRF jittering: PRF switching involved calculating the actual range by noting how far the unambiguous range and changed versus how many range bins the target changed for a given PRF change; PRF jittering involved changing PRFs and discarding any targets that changed bins (only targets at their true range don't change bins).

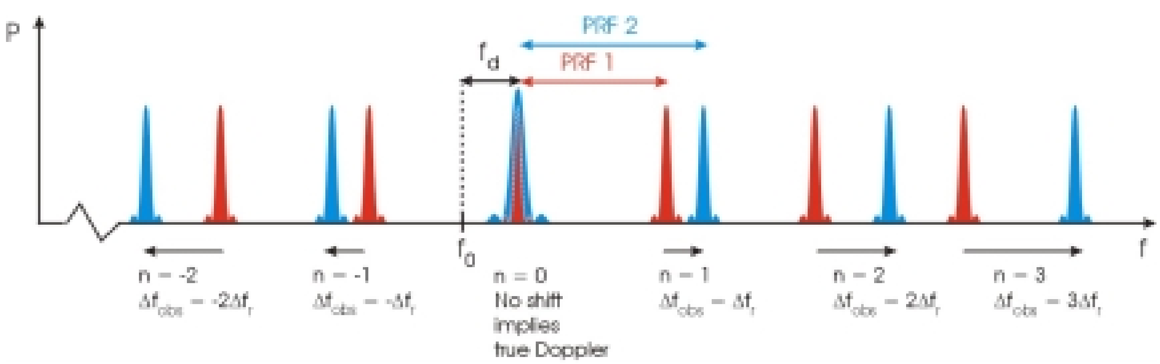
Range ambiguity equations: $R_{true} = nR_u + R_{apparent}$

$n = \Delta R_{apparent} / \Delta R_u$

Doppler ambiguity equations: $f_d = n\, f_r + f_{observed}$

$n = \Delta f_{observed} / \Delta f_r$

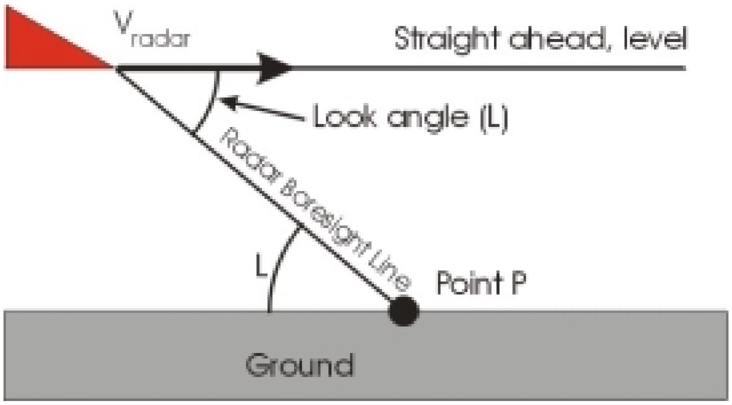
Show example on board:



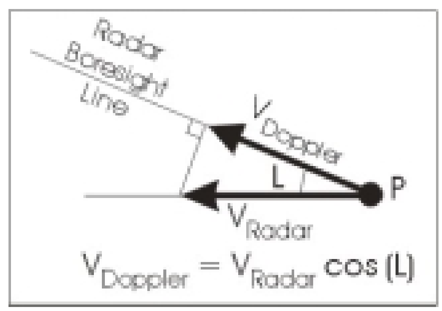
For resolving range, you almost always had to do the "n" calculation (PRF Switching) to get the exact range, but since our filter passband was designed to cover all probable Doppler shifts, we can simply jitter and see which return doesn't move! We know it will be in one of the filters – the only question is which return is the true return.

So far, we've examined only no-noise/no clutter examples where our only return was from the intended target, or from a localized, large ground return. In the real world, things aren't so easy!!

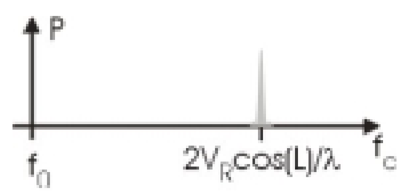
Let's take a look at what the ground return (ground clutter) from the main beam of the radar will look like if it's aimed slightly downward from a jet in level flight. What is the velocity of the point P on the ground that the radar will see? The only velocities that radars can see are *radial* velocities, the velocity of the target toward or away from the radar. Cross velocities (velocities perpendicular to the direction of motion) can't be directly calculated. Only radial velocities affect f_d, so we need to find the projection of the fighter's velocity on the radar boresight line.



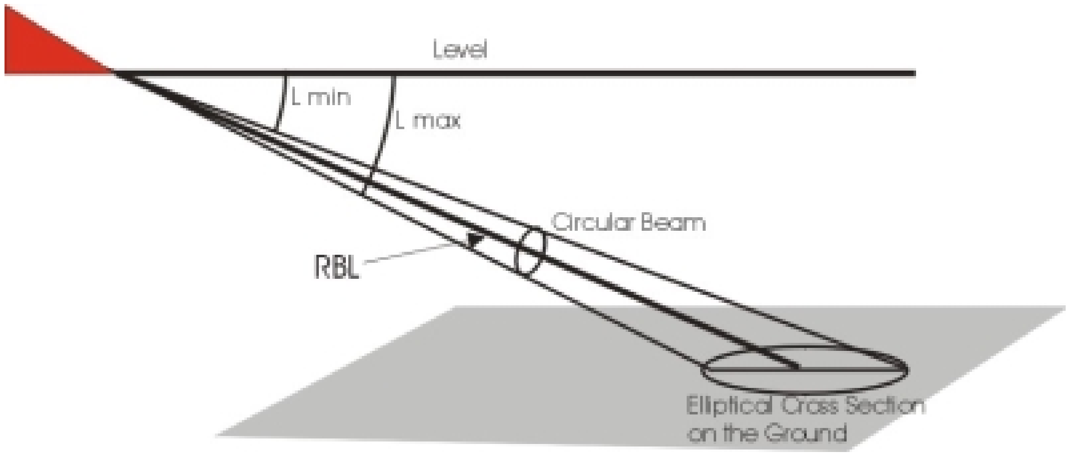
L = Look angle
V_d = Doppler velocity sensed by the radar
V_R = Velocity of the radar
$V_d = V_R\cos(L)$
This implies that for the limiting angles of 0 and 90 degrees: for L = 0, $V_d = V_R$; for L = 90, $V_d = 0$.



From our formula for the Doppler shift, our general Doppler speed for point P, $V_R\cos(L)$, has a Doppler shift of $f_d = 2\dot{R}/\lambda = 2(V_r\cos(L))/\lambda$. This analysis then implies that the ground clutter from point P should look like a single line on the frequency spectrum (note the horizontal origin is now f_0):



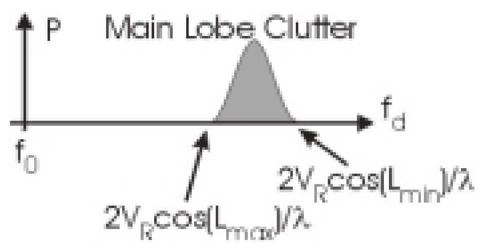
But the beam has *width*, too. It doesn't just hit one point on the ground…



So V_d seen by the radar has a *range* of values

$$\begin{array}{l} V_{d\,max} = V_R \cos(L_{min}) \\ \underline{-[V_{d\,min} = V_R \cos(L_{max})\ ]} \\ \Delta V_d = V_R(\cos L_{min} - \cos L_{max}) \end{array}$$

This shows that instead of a single line for ground clutter from the main lobe, there will be a range of frequencies in the return:



How does this equation vary with L? Let's look at two cases: L = small (about 5deg) and L = big (about 55 degrees)

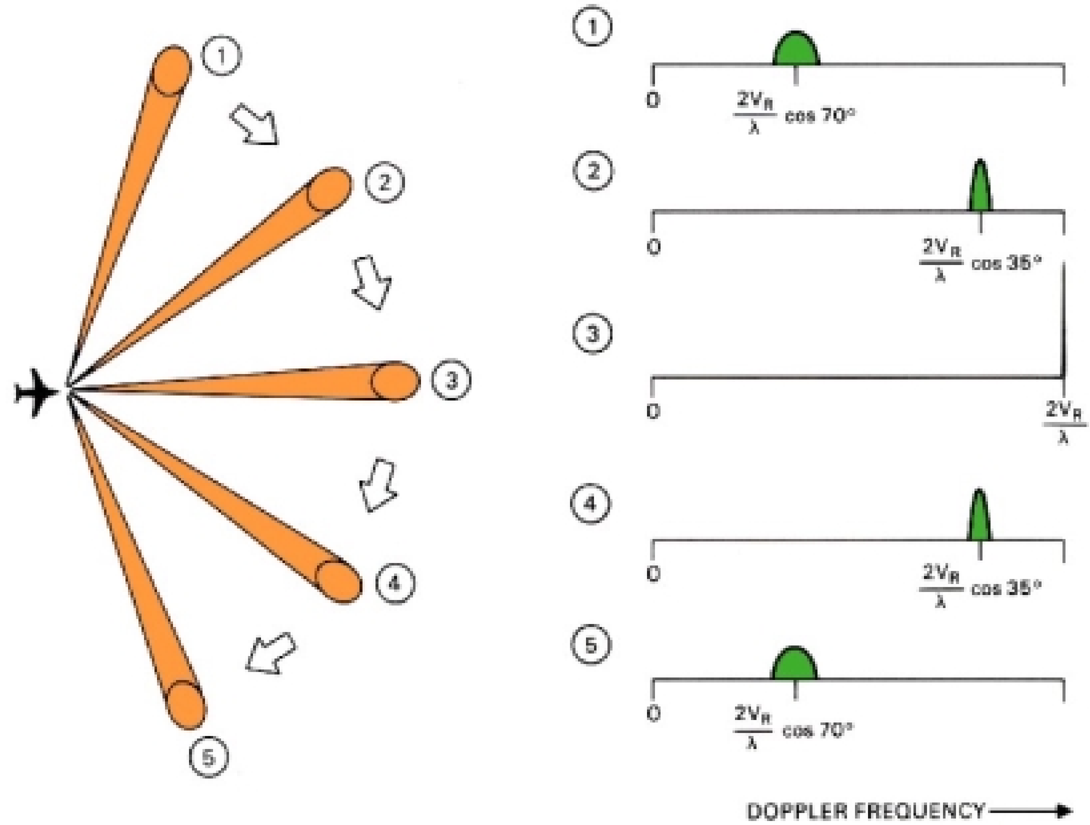
L = 5: L_{min} = 4deg, $\cos L_{min}$ = 0.99756
L_{max} = 6deg, $\cos L_{max}$ = 0.99452 $\cos L_{min} - \cos L_{max} = 0.00304$

L =55: L_{min} = 54deg, $\cos L_{min}$ = 0.58779
L_{max} = 56deg, $\cos L_{max}$ = 0.55919 $\cos L_{min} - \cos L_{max} = 0.02860$

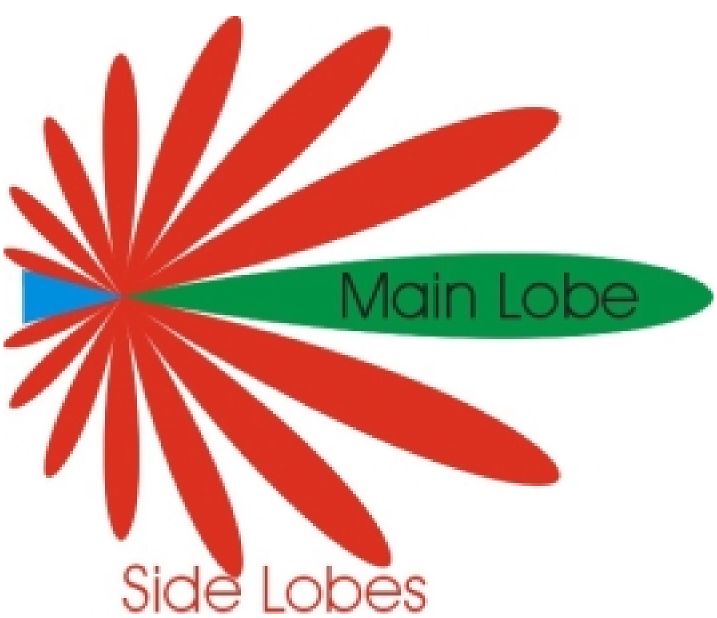
0.02860/0.00304 = 9.4 So the spread in sensed velocities is nine times larger for this large look angle than for the small one.

Let's summarize: Small look angles have high Doppler shifts and small Doppler spreads. Large look angles have low Doppler shifts and large Doppler spreads.

Not only does the width of the main lobe clutter return “breathe” (get wider and narrower) as the radar moves up and down, it also breathes as it moves side to side:



Explain “breathing” of the return as it sweeps back and forth.

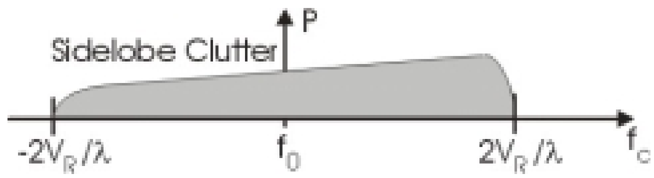


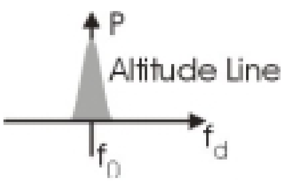
So that’s all there is to clutter, right? Not quite! What does diffraction do to a radar beam? It forms sidelobes. Sidelobes have returns, too!

The angles at which they occur are approximately straight ahead of (±2deg) to straight <u>behind</u> the aircraft, with the powers of each side lobe decreasing as the angle from boresight increases. What is the maximum spread of the clutter, ie, what Doppler frequencies should we expect our clutter return to encompass?

$\Delta V_d = V_R \cos(0) - V_R \cos(180) = 2V_R$
$\Delta f_d = 4V_R/\lambda$, centered at $f_d = 0$; thus the clutter spectrum should then run from $-2V_R/\lambda$ to $2V_R/\lambda$.

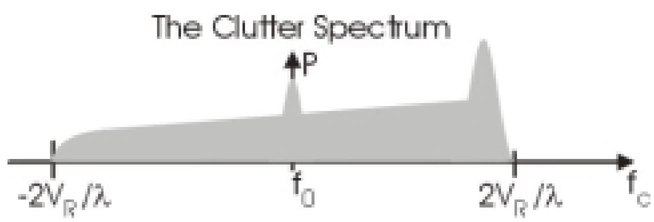
Higher order sidelobes emit much less power than lower order ones, but their ranges to the ground are generally much less, too. Thus we can draw an approximate sidelobe clutter diagram like this:





A special case of sidelobe cutter is when the lobe points straight down. The range from the radar to the ground through this lobe exactly equals the radar's altitude. This range is also the minimum range to the ground that any part of the diffraction pattern sees. Since the amplitude of the return is proportional to $1/R^4$, the intensity of the return is proportional to $1/R^8$, so by minimizing the range, the intensity grows sharply. Thus, there is a very large clutter return called the altitude line at $f_d = 0$ (for level flight). At low altitudes, this return may be even stronger than the main lobe clutter.

Putting together the three parts of the clutter spectrum, we get this shape:



Discuss: targets vs. clutter
Does the altitude line always occur near $f_d = 0$?
How is the altitude line/sidelobe clutter minimized?
What if you are using range gates?
What if you have a large/small number of frequency filters?

You should be able to tell me what happens to the shape of the spectrum if the plane climbs, dives, sweeps the antenna from the front to the side, etc.